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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

PROGRAM PLAN

FOR

TERMINAL CONFIGURED VEHICLE PROGRAM

Langley Research Center

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TABLE OF CONTENTS

TERMINAL CONFIGURED VEHICLE PROGRAM

A. BACKGROUND AND JUSTIFICATION

A number of recent government and industry studies concerned with the policy, operations, and research and development aspects of Civil Aviation (references 1 through 5) have identified a variety of problems requiring solution in order to improve this vital mode of worldwide travel and communication. Some of the prime problems identified were: safety, economics, noise, congestion, delays, chemical pollution, etc. Most of these problems are associated with the terminal area of the system and are already acute at the major airports. Attention is therefore required in terms of both short-term alleviation and the development of advanced system approaches to permit the air transportation growth which is projected over the next decade.

The anticipated air transport situation in the 1980-1990 decade has been considered in many studies (ref. 1, 4, 6, and 7, for example). Although differing in expected magnitude, all such studies predict continued traffic growth by factors of 2 to 3 by the year 1985. Of particular concern is the increase in the number of flight operations which will occur despite the introduction of aircraft of increasing passenger and cargo capacity.

The problems which have become critical in today's air transport system can be expected to intensify with increased traffic. Reference 4 indicates that by 1980, 4 airports will have become saturated, and that by 1990, 16 will have become saturated. The resulting congestion causes both traffic disruption and delays which are costly to the airlines by reducing productivity and are aggravating to passengers. Low visibility weather amplifies the problem by reducing the landing rates in IFR conditions. By measurement, 89% of delays over 30 minutes are attributed to weather (ref. 8). It is estimated that the cost of delays to one air carrier operating 1000 flights per day is $5 million per month of non-productive utilization (ref. 8). Reference 4 states that delay cost to the air carriers amounted to roughly $160 million per year in 1969 and is estimated to reach a rate of $1 billion per year in 1981. Caution should be exercised in the use of delay time statistics. When repetitive delays are encountered in scheduled flights, it is customary to alter schedules to include expected delays (ref. 8), causing increases in block-to-block time. Reference 9 illustrates such increases in block-to-block time for one airline between 1965 and 1970. Whether considered as reduction in delays or block time, the alleviation of the basic terminal area congestion problem will provide substantial benefits in productivity of aircraft and the air traffic control system. This will result in reduced costs, conservation of energy resources, and reduced atmospheric pollution.

Aircraft safety is of continual concern to the airlines, regulatory agencies, and the traveling public. Although the scheduled airline safety record is among the best in the mass transportation industry, improvements can still be made, particularly in terminal area operations. Increased emphasis on the use of aircraft with large passenger capacity stresses the need for improved safety.

The approach and landing phases of flight account for more than half of all fatal accidents. Low visibility weather is a major contributing factor in such accidents. In addition to the loss of human life, considerable economic loss results from the destroyed aircraft and the settlement of passenger claims. Improved safety is thus an important part of improved terminal operations.

The need for reduced noise impact hardly needs justification since restrictions already exist at some airports and as air traffic and the population density near airports increase, noise impact will have an even greater influence on restrictions, amplifying the problems of traffic disruption and congestion. Both near term and far term solutions must be found.

In their continuing programs to provide solutions to the aforementioned problems, the Department of Transportation and the Federal Aviation Administration have initiated development activities to provide advanced ground facilities and air traffic control systems. For example, DOT-FAA is leading a national effort, reference 10, to develop a new microwave landing system which should improve operational capability, help provide flexibility in selecting curved approach paths to avoid noise sensitive areas, and aid in implementing flow management and sequencing techniques to handle traffic more efficiently. Similar efforts are planned in upgrading other elements of the air traffic control system and in examining air traffic management concepts for the future (reference 1). Improvements in the operational safety and efficiency will be realized as the DOT/FAA developed advanced ground-based elements are introduced into service. However, corresponding improvements must also be accomplished in the airborne portion of the system. Towards this end, the NASA has established the Terminal Configured Vehicle (TCV) Program to complement the DOT/FAA and supporting industry activities aimed at providing solutions to the safety and growth problems associated with the terminal area.

B. BROAD PROGRAM OBJECTIVES

The TCV Program is an advanced technology activity focused on Conventional Take-off and Landing (CTOL) Aircraft that will be operating in reduced weather minima in the future high-density terminal areas equipped with new landing systems, navigational aids, and increased surveillance and automation under development by DOT/FAA.

The broad objectives of the program are to provide improvements in the airborne systems (avionics and air vehicle) and operational flight procedures for reducing approach and landing accidents, reducing weather minima, increasing air traffic controller productivity and airport and airway capacity, saving fuel by more efficient terminal area operations, and reducing noise by operational procedures.

In terms of avionics, this involves significant improvement over current systems in the areas of automatic flight controls and pilot displays in order to take full advantage of the flexibility of the new landing systems being developed, and to reduce pilot workload so that operational safety is enhanced. In terms of vehicle design, this may involve changes to improve the capability for precise speed and flight path control and for reduced landing and take-off distances. Continued attention will be given to related NASA programs being undertaken to reduce wake vortex effects which are a major constraint on terminal area operations.

During the program, emphasis will be placed on the development of operating methods and systems for the highly automated environment which is anticipated in the future. This involves research analyses, simulations, and flight studies which will be conducted primarily at the Wallops airfield. A modified Boeing 737 airplane, which is equipped with highly flexible display and control equipment being made available by DOT-FAA, will be used to study operations in simulated future terminal area environments. This aircraft is referred to as the Research Support Flight System (RSFS). Flight modes including terminal area maneuvers, final approach, landing, and rollout will receive attention as illustrated in figure 1. At key points during the program, flight activities will be conducted with participation by personnel from the airlines and the aircraft industry. The intent is to obtain the best ideas of operating personnel and to encourage acceptance of new concepts that may be developed. An overview of the major program elements is shown in figure 2.

Throughout the program, active coordination will be maintained with DOT-FAA and DOD. Particular emphasis will be given to compatibility with the microwave landing system under development by DOT-FAA and with future air traffic control systems. Also, attention will be given to cooperative efforts involving the use of the specially-equipped test aircraft in support of other current FAA development programs subject to compatible time and schedule arrangements. Coordination and technical exchange will also be maintained with the airlines, and the manufacturers of aircraft and aircraft systems.

C. RELATIONSHIP TO NASA/OAST GOALS

The TCV Program is being conducted by the NASA Office of Aeronautics and Space Technology to be responsive to the national needs for an efficient, safe, economical and energy conservative air transportation system which will meet with community acceptance. It is a focused technology effort which addresses several discipline areas under the cognizance of OAST. The major OAST discipline areas are aircraft operations research, aircraft operating systems technology, ATT systems studies, and human factors. In addition, studies will include aerodynamic and propulsion system elements which may contribute to solution of terminal area problems. The TCV Program has primary relevance to the following vertical cut areas of emphasis: Terminal Configured Vehicle Technology, Advanced Transport Technology, Reduce Aircraft Noise, Reduce Terminal Congestion, Aeronautical Energy Conservation, and Aviation Safety. It has applicable relevance to Reduce Aircraft Air Pollution.

D. TIMELINESS

In order to provide the system operating technology in a timely and effective manner, the TCV program will undertake to identify gaps in the current technology of operating systems (such as displays, automatic controls, and aircraft performance requirements), and generate solutions which will permit safer and more efficient terminal area operations. It is important that the TCV Program be conducted in a time frame that is compatible with planned improvements in the National Airspace System. In order that the advanced airborne technology and systems required to interface with the future ATC system being developed under FAA leadership are available by the mid-1980's, they must be essentially demonstrated by the late 1970's. The planned schedule of TCV activities is designed to accomplish this purpose.

E. SPECIFIC OBJECTIVES AND TARGETS

The broad objectives of the program will be accomplished by developing and demonstrating technological advances in systems and procedures for terminal area operations by means of the specific objectives and targets enumerated below:

Improve Productivity and Safety

(1) Zero-visibility landing capability by improved precision automatic control, primary displays (monitoring/manual control), and independent landing assessment systems.

Target: Basic capability for IFR landing rates approaching VFR rates by 1977.

(2) Increased airport acceptance rates by reduced longitudinal spacing and by improved threshold arrival accuracy, improved tracking for lateral spacing, and reduced runway occupancy time. Demonstrate capability of aircraft and guidance and control systems to achieve 4D flight path position accuracy required to accomplish these objectives.

Targets: Techniques for 4D control permitting: longitudinal separation between aircraft of 2 miles or less, arrival accuracy of ± 5 seconds, and lateral runway spacing of 2500 feet by 1976; reduction in runway occupancy time to 25 seconds by 1977. There is confidence that research efforts underway on wake vortex alleviation or detection and possible avoidance procedures will permit utilization of these capabilities by the mid-1980's.

(3) Reduced workload by improved flight deck design, better understanding of crew coordination and individual tasks, and automation.

Targets: Display and control methods for acceptable CAT III automatic operation utilizing MLS capabilities by 1976; pilot workload reduced by 25% by use of time-line analyses; approach and landing accident reduction potential by 50%.

Reduce Environmental Impact

(1) Avoid noise sensitive areas by use of curved approaches and departures, and reduce source intensity by use of steep and/or decelerating paths.

Targets: Development of approach and departure methods, displays for automatic systems, and guidance techniques for 1975; establish noise reduction magnitudes for curved and decelerating approaches by 1976.

(2) Operational procedures to reduce atmospheric pollution and permit fuel savings.

Targets: Evaluate effects of reduced delays, reduced flight times, steep decelerating paths, reduced runway occupancy time, and powered wheels by 1977; potential reduction in terminal area annual fuel wastage by 25%.

Support Current FAA Programs

(1) Cooperate with FAA in-flight testing for:

- EADI Evaluation
- CAT III Data Collection
- MLS Utilization

Target: Initial EADI evaluation by 1974; other elements as appropriate; overall technology availability by 1978.

Other Activities

(1) Support or encourage other programs and studies such as:

- RTOL Characteristic Investigation
- Wake Vortex Reduction
- Active Controls Integration
- Man-Vehicle Technology

Target: Determination of benefits and costs of aircraft and procedural modifications for improved terminal area operations by 1978.

F. TECHNOLOGY PLAN

A schedule of the key program activities, including simulation, flight test, and supporting studies and evaluation, to be conducted at both the Langley and Wallops Station facilities, is presented in figures 3 and 4. Initial emphasis will be placed on analytical and experimental studies to define operational systems requirements and identify areas where technology development activities should be undertaken. Since simulation and flight evaluation will be the primary tools in carrying out this effort, much of the early activity has been concerned with the procurement of advanced research equipment required and upgrading existing test facilities to carry out the program. In mid-1974, facility acquisition will be completed and the research elements of the program will be initiated.

The Research Support Flight System (a Boeing 737), shown in the photograph of figure 5 and schematically in figure 6, will be equipped with highly flexible display and automatic control equipment to study and develop advanced operational techniques such as curved, decelerating approach paths with extensive use of automation in simulated future terminal area environments including advanced area navigation and microwave landing systems. The Aft Flight Deck (AFD) shown in figure 6 provides an experimental environment that is more flexible and easily controlled than the normal Forward Flight Deck (FFD). The AFD is an autonomous unit not required for flight of the basic airplane; therefore, it is dedicated to experimental research on advanced systems and concepts. Because of this dedication, the configuration of the AFD can be more easily tailored to each experiment. The constraints imposed by space, structural, and flight safety considerations are significantly relaxed in the AFD. It will permit two man crew experiments not possible in the FFD because of the requirement for safety pilot and basic/back-up flight instruments.

The activities associated with development of an advanced integrated system for flight demonstration (figure 2) are not presently included within the projected resource requirements. Flight demonstrations to the air transport community could be made with an experimental system. However, credibility of results and acceptability by airlines may depend on demonstrations with an integrated system of a design which would satisfy all the requirements for a supplemental type certificate when used with the RSFS airplane.

In addition resource requirements do not yet include provisions for modifications to the RSFS airplane, controls, and propulsion system for wake vortex reduction, noise abatement, more efficient terminal area operations, etc. These provisions will be added when promising modifications are identified.

F.1 TECHNOLOGY ELEMENTS

The key technology elements which are involved in the program are described in the following sections:

F.1.1 SYSTEMS ANALYSIS AND INTEGRATION

It will be necessary to maintain a continuing effort on overall systems analysis of all the elements which influence the terminal area environment. Initial work will make use of studies of terminal area compatibility which are being conducted under the closely related program on Advanced Transport Technology discussed further under F.4.1.

F.1.2 COMPUTER SIMULATION ANALYSES OF TERMINAL AREA OPERATIONS

The objective of this effort is to determine the aircraft performance and control system characteristics needed to alleviate noise and improve productivity in terminal areas with advanced air-traffic management concepts. The LRC computer simulation capability currently being utilized in this study models a typical terminal area and contains elements to realistically represent: (1) airborne navigation equipment, communication systems, and the primary aircraft sensors; (2) the ground navigation aids, data links, radars, airport configurations, traffic situation displays, ATC procedures, enroute flow control information, runway and airspace constraints; and (3) models of traffic samples and aircraft performance characteristics, and constraints on maximum descent, turn, and climb rates, maximum g's, etc. The present terminal area simulation capability will be expanded to include models of the upgraded third-generation ATC system and other advanced concepts. Fast-time simulations will be used to determine candidate concepts for flight path control. Analytical models of the B-737, MLS characteristics, and wind effects are currently being developed. These simulations will assess the performance required of the aircraft and selected airborne systems operating in a simulated air traffic environment of a typical terminal area. Real-time simulation experiments with "pilot-in-the-control-loop" will be conducted to verify candidate system concepts which take maximum advantage of the pilot and aircraft performance characteristics and to analyze the flight safety margins. These efforts will identify technology deficiencies which are most critical and where R & T activities can be most profitably applied. Subsequently, the RSFS aircraft, flying at the Wallops Station, will be included in the terminal area situation studies via the LRC-Wallops data tie-line.

F.1.3 LANDING DISPLAYS

Although automatic landing systems have been developed and automated landings are made routinely during good weather conditions, this capability is not being used extensively in commercial airline operations during low-visibility conditions due, in part, to the lack of confidence by the pilot in his ability to adequately assess the performance of the on-board systems and the aircraft's situation relative to the runway. This situation becomes more critical in the curved track, sequenced, and possibly decelerating approaches in the advanced environment being considered.

Preliminary requirements for primary flight control display information and formats will be established through a cooperative DOT-FAA/NASA evaluation of the FAA/SST display system (ADEDS); and by consultation with NASA, DOT, and DOD personnel, the aviation industry, commercial airlines, and airline pilots. Requirements will be updated as results of study, simulation, and flight testing become available. These requirements will include a definition of the information (position, attitudes, rates, command and predictive information, etc.) required by the pilot to enhance his performance, and the format required for effective assimilation of this information.

Concurrently, in-house simulation studies of advanced display requirements are being conducted. The research displays used have built-in flexibility to permit manipulation of such items as display and computer formating and system interfacing.

Flight research evaluations for the most promising concepts identified in simulation studies will be conducted at Wallops Station in the RSFS airplane. Final assessment will be conducted over curved, steep, decelerating approach paths under low-visibility conditions.

One of the reasons for limited acceptance of autoland capability has been the lack of a system, operating independently from the primary guidance system, to provide the pilot a separate source for assessing the performance of the primary system and the aircraft situation. Work is currently underway on several such systems and some flight evaluations have been made elsewhere. As part of the TCV Program, a study of the requirements of an independent landing assessment system for civil air transport operations will be made. The study will investigate candidate systems considering the effects of advanced flight procedures. Flight tests of a selected system will be made to evaluate its usefulness and determine pilot acceptance.

F.1.4 MICROWAVE LANDING SYSTEM (MLS) UTILIZATION

The MLS which is being developed under the leadership of the FAA is considered an essential element of the advanced total system for future terminal area operations. The existing FAA program will provide for basic MLS system development and lay the groundwork for its initial use by the airlines. Under the TCV Program, emphasis will be placed on the development of advanced airborne systems and flight procedures designed to exploit the capabilities afforded by the MLS.

Analytical models are being developed for the MLS and will be used with terminal area cockpit simulators to study information utilization and display techniques for automatic, semi-automatic, and full-manual flight modes.

Flight studies will be conducted using the Wallops Station FPS-16/Laser Tracker to generate MLS-like guidance information. These flights will permit evaluation of conceptual aircraft operating system functions and procedures over the wide range of MLS parameters. In the later phases of the program, the prototype MLS installed at NAFEC may be used to evaluate experimental aircraft equipment and to demonstrate overall system operations.

F.1.5 AUTOMATIC FLIGHT CONTROL SYSTEMS

Reliable automation will be necessary to implement the flight path control and landing operations required to maintain rigorous schedules independent of weather and provide acceptable capability for following the complex paths which may be needed for sequencing and noise abatement. This automation will utilize the advances in airborne digital control and computing technology which are being pursued under other programs (digital fly-by-wire, active control technology, and related military efforts) along with the development of control laws which are suitable for various levels of automation and pilot participation in the future flight environment. Simulation and flight studies utilizing models currently under development will be used to determine the tracking precision and the flight path and speed control capabilities which are required, and to investigate techniques for implementing various levels of automation for the final approach, flare maneuver, touchdown, and rollout under low-visibility conditions. As the requirements become understood for these advanced operating methods, emphasis will be placed on the development of efficient control laws which can be implemented in a manner that will be compatible with the advanced display and landing assessment requirements which were discussed earlier. Particular attention will be given to system mechanization so that satisfactory operation is achieved with a variety of electronic and system degradations and to ensure freedom from the possibility of system failure resulting from single point failure.

F.1.6 FLIGHT DECK DESIGN

Integrated flight deck functions will be required to ensure effective pilot/aircraft operation in the dense traffic and complex terminal area environment. Technology is available to develop integrated, time-shared, computer-generated cockpit displays and to introduce new control devices such as brolly handles, side-arm controllers, and keyboard access to computers.

The goals of an integrated flight deck system design are to decrease crew workload, and to increase system accuracy and performance while maintaining the necessary pilot proficiency, system reliability, and safety. The design elements to be considered include:

(a) Degree of automation

(b) Crew coordination and tasks

(c) Aircraft system status monitoring

(d) Runway, ground, and avionics equipment status

(e) Flight status and progress information

(f) Layout of cockpit system

Ground-based and in-flight cockpit display research facilities at Langley will be upgraded to permit the simulation, in real time, of integrated, pictorial, and graphic, multi-mode cockpit displays on high-resolution CRT's.

Investigations will be conducted on the changing role of the pilot from sensor/controller to monitor/manager as increasing degrees of automation are introduced into the flight control system. Laboratory, simulator, and flight studies will investigate overall subsystem design including computer requirements and interfaces, methods for efficient interactive control and display and generation methods for efficiently addressing CRT's.

Experiments will also be based on results of studies and analyses of approach and landing accidents to assure that the overall objective of enhancing flight safety is attained.

F.1.7 AERODYNAMICS AND AIRCRAFT CONFIGURATION

The performance characteristics of aircraft and their systems offer an important potential for alleviating noise and pollution, increasing airport capacity, and reducing delays at major airport terminals. Implementation of upgraded ATC systems with their capability for efficiently directing higher density traffic requires aircraft incorporating advanced technology to ensure that the aircraft and its systems are responsive to the control and precision requirements of the ATC system. Some of the major aircraft-related considerations include the trailing vortex problem, noise generation, precise speed and flight path control in all-weather conditions, and low-speed handling qualities. Results of contractual terminal area compatibility studies for the ATT Office will furnish initial inputs into this effort. Aircraft design and system features will then be investigated to determine their contribution to improved performance.

Reduced Take-Off and Landing Capability (RTOL) will permit expanded utilization of existing airports. An RTOL capability is considered one that permits operations from field lengths of 4000 to 5000 feet. Initially, the work in this program will consist of studies to evaluate option for alterations to the aircraft and its propulsion system to achieve RTOL capability, and the effect on terminal area operations. This will be followed by efforts to determine costs and feasibility of such alterations. Decisions on modifications of the RSFS aircraft to provide RTOL operations will be made after the studies have identified the operational benefits and costs. Currently projected funding requirements do not include such modifications.

F.2 FLIGHT EXPERIMENTS AND RELATED SIMULATION STUDIES

Present efforts at LRC have concentrated on definition and preparation of facilities and planning an initial group of experiments which are concerned with advanced displays, automatic systems, and operating methods. The currently planned activities and schedule are shown in figures 3 and 4. Initial flight experiments and simulation studies have been designed to evaluate an advanced display and control system (developed under FAA SST Follow-On Technology Program) which is installed in the RSFS, and to obtain baseline performance data on the RSFS and other test facilities at LRC and Wallops Station. These experiments and studies are listed below:

(1) Seattle, Washington (Moses Lake Area) - Nov. 1973 - Jan. 1974

(a) Advanced Electronic Display System (ADEDS) - Dec. 1973
Evaluation flights of advanced displays utilization in area-navigation flights, manual curved approaches, and manual approaches in low visibility will be conducted.

(b) Automatic Guidance and Control (AGCS) - Feb. 1974
Initial tests will be made to assess failure mode effects and evaluate fail operative autoland, sensor voting techniques, flight path angle control wheel steering (CWS), track angle CWS, velocity vector CWS, and transition from R-NAV to ILS.

(c) RSFS Aft Cab Checkout - April 1974
Tests will establish total system operability and will constitute the basis for NASA vehicle acceptance tests.

(2) Langley Research Center/Wallops Station - July 1973 - Dec. 1974

(a) Noise Documentation Flights
Initial flights were made to document approach and take-off noise characteristics over the Wallops Station Range.

(b) Facilities Checkout
Data acquisition and tracking radar/laser facility checkout, pilot familiarization, and technician familiarization will be accomplished.

(c) Flying and Handling Quality Documentation
Research Support Flight System Flying and Handling Qualities documentation flights will be conducted for simulator checkout and comparison with postulated requirements.

(d) Manual Landing
The effectiveness of ADEDS in improving approach performance and preliminary formats for landing displays will be investigated.

(e) Autoland Performance on ILS-type Guidance
The effects of weather, wind shear, turbulence, and crosswind on autoland touchdown envelopes, and performance monitoring tasks will be investigated.

(f) Flight Management and Path Limitations
Terminal area maneuver limits as affected by piloting problems, aircraft performance, and passenger acceptance will be identified.

These initial flight activities are expected to utilize approximately 200 flight hours through December of 1974.

It is anticipated that a number of flight experiments will be undertaken in support of near-term FAA needs and that the FAA will take a lead role in defining such experiments.

A planning activity is currently under way at Langley to develop details of the research program experiments and tasks beyond November 1974. These tasks and experiments are being reviewed by the Flight Experiments Working Group for relevance and completeness. Discussions with the FAA at the working level have been initiated and planning sessions scheduled. Continuing interface with the FAA is essential so that support requirements can be identified on a timely basis.

An interim flight simulator has been assembled to examine the potential of electronic displays in aiding the pilot in performing the complex tasks envisioned for the future terminal area environment. The tasks identified for study in the simulator are:

(1) Display Studies

3D and 4D terminal area navigation, manual approach to land, MLS formats and data rates, initial display requirements for curved, descending decelerating approach and landing in Category III conditions will be investigated.

(2) Control Techniques

Control law verification, crew roles and duties, side arm controls and other advanced control features, new piloting techniques, and energy management approaches will be investigated.

F.3 MAJOR INTERFACES

F.3.1 LANGLEY-WALLOPS STATION INTERFACE

The Wallops Station Airport will be utilized for much of the flight activity in this program. It permits a high volume of research on approach and landing problems since the contiguous airspace is controlled by the NASA. A modern control tower, as well as fire, crash, and rescue services, are available on a full-time basis. The station has all the required research support facilities such as meteorology, photography, and computer systems, in addition to hangars and housing, if required.

Facilities at Langley and Wallops which include the RSFS, the Guidance Simulation Facility (FPS-16 and Laser Tracker to simulate MLS) and the Display Research Facility will be integrated through a data link as shown schematically in figure 7. This linkage will permit the terminal area ATC simulation at LRC and at NAFEC to be included with the Terminal Area Display Research Facility and aircraft under test, and will allow the aircraft to be flown under controlled conditions in a representative air traffic environment. The system will be used for a realistic opportunity to study total system performance and interactions. The two way data link between Langley and Wallops will be installed with OTDA funding. All of these facilities are currently being implemented.

Close liaison with Wallops will be maintained to insure proper scheduling of flight studies, as well as optimum utilization of the available precision instrumentation.

F.3.2 GOVERNMENT-AIRLINES-INDUSTRY INTERFACES

The successful accomplishment of this program depends upon active coordination with, and participation of, those segments of Government and industry which are concerned with the air transportation system.

F.3.2.1 GOVERNMENT

The primary government interfaces will be with the DOT and FAA, including the FAA-SRDS, FAA-SST Office, and the Transportation Systems Center (TSC). A memorandum of agreement has been signed by NASA and DOT/FAA for cooperative efforts in programs planned to improve terminal area operating capability for conventional transport aircraft (reference 11). Areas requiring particularly close coordination will be those related to development of the microwave landing system, the avionics technology being developed following the termination of the SST program, and the definition of an advanced air traffic control system.

F.3.2.2 INDUSTRY

A continuing effort will be made to obtain the assistance and participation of the airlines, airline pilots, airframe and engine manufacturers, and the avionics industry during the program. This will insure that their unique requirements are identified and integrated into the program, will provide assistance in evaluations of experimental and demonstration systems, and will develop means by which they can more actively participate as the program progresses. For example, airline pilots will be invited to participate in both ground simulation and flight experiments at Wallops Station through the medium of the RTAC Advisory Panel and Flight Experiments Working Group.

F.4 RELATED ACTIVITIES

F.4.1 ADVANCED TRANSPORT TECHNOLOGY SYSTEMS STUDIES

As mentioned previously under F.1.1, NASA has recently sponsored systems study contracts with major commercial transport manufacturers. These studies indicate how the use of advanced technology in long-haul transports can provide operational benefits, such as improved performance and reduction of the penalties associated with noise alleviation. Since the studies have shown that these benefits may be applicable to a wide range of subsonic and sonic aircraft, further evaluations have been initiated which consider the economics, environmental impact, and terminal area operations.

A Terminal Area Compatibility Study for C/RTOL aircraft is being conducted to determine the impact of future terminal area operations and procedures on advanced aircraft configurations and characteristics. The objective of this study is to identify the aeronautical aspects of advanced long-haul subsonic transports which could alleviate the noise, emission, safety, low visibility, and congestion problems in the terminal area portion of the U. S. National Airspace System during the 1980 - 2000 time period, to estimate the probable costs involved, and to identify the areas in which R & D efforts should be initiated. Follow-on studies will consider terminal compatibility factors for shorter range C/RTOL aircraft.

F.4.2 VORTEX DISSIPATION

Experimental studies are underway in wind tunnels and water tanks to identify practical methods for dissipating wing-tip vortices to permit reduction of the separation distance between aircraft. Spoilers, drogues, wing-tip blowing, tip-mounted engines, and oscillating flaps are examples of devices being investigated. The most promising concepts identified in these studies will be considered as candidates for flight testing. The first such effort will take place in late 1973 and consists of flight tests of a Wallops C-54 aircraft equipped with towed splines at each wing tip for vortex dissipation. A smaller airplane will be used to probe the wake of the C-54 to evaluate the effects of the splines on the response of a following airplane making a vortex penetration.

F.4.3 NASA/FAA STOL OPERATING EXPERIMENTS PROGRAM

The STOLAND program discussed in reference 12 being carried out principally by Ames as the cognizant NASA Center, will be reviewed continuously to determine what portion of the technology developed for STOL vehicles can be profitably applied to the TCV Program. It is also anticipated that valuable inputs will be derived from the current joint LRC/NAFEC STOL operations simulation studies.

F.4.4 ACTIVE CONTROL TECHNOLOGY

An extensive program is being planned by NASA to investigate and demonstrate by analysis, simulation and, where appropriate, flight testing the benefits to be derived from active control systems. Much of the active control program emphasis will be on items like flutter suppression, maneuverload alleviation, and relaxed static stability. However, developments in control theory and airborne computing technology from this work and the closely related Digital Fly-By-Wire program, discussed in reference 13, are expected to have direct application in the development of control systems for automation of approach flight paths. A study is planned to determine the suitability of the RSFS for experimental evaluation of certain active control concepts during the latter part of the TCV Program.

F.4.5 MICROWAVE LANDING SYSTEM

A new Microwave Landing System (MLS), discussed in reference 10, is presently being developed by the FAA with DOD and NASA participation. This system will provide volumetric position coverage that will permit curved flight paths. This new system should permit optimized flight operations designed to reduce noise exposure around airports, permit more closely spaced runways, increase airport and airspace capacity, improve safety, and permit improved operations in low vision (Category III) conditions. Utilization of this capability in the TCV Program has been discussed in section F.1.4.

F.4.6 VTOL AUTOMATIC LANDING TECHNOLOGY (VALT)

Langley has initiated a program to develop and demonstrate the technology base needed in establishing systems design concepts and operating procedures for VTOL short-haul transportation systems in the 1980 time period. This effort will focus on the navigation, guidance, control and flight management systems. Joint use of facilities at LRC and Wallops will be made by this program and TCV, resulting in cost savings.

F.4.7 AERONAUTICAL MAN-VEHICLE TECHNOLOGY

Man-vehicle (human factors) technology is an essential part of the TCV Program from at least two viewpoints: Integrating the flight crews with the advanced terminal configured vehicle, and insuring research and technology focused on drastic reduction of pilot-error related aircraft accidents. The aft flight deck of the RSFS provides a unique research facility for conducting experiments which are man-vehicle related, as a follow-on to research with ground-based simulators.

F.4.8 OTHER RELATED ACTIVITIES

A joint FAA/NASA VLF (Omega) Navigation System Test Program, discussed in reference 14, is being conducted with Langley as the cognizant center and with flight tests from Wallops Station. This program will be followed closely for possible inputs to the TCV Program.

The Langley research program on fault-tolerant computer technology will also provide important inputs to this effort.

F.5 ANALYSIS OF ENVIRONMENTAL IMPACT

It is considered that the TCV Program will not result in any undesirable environmental impact. In this regard, the following points should be noted:

(1) Standard passenger-type aircraft will be used in the flight program. No special propulsion equipment will be used and no emissions or noise above those for current airline operation will occur.

(2) Flight operations at Wallops will be in a relatively remote area with only a low population density.

(3) A significant feature of the program is the development of procedures to reduce noise. In this respect, the environmental impact will be favorable.

G. MANAGEMENT APPROACH

G.1 ORGANIZATION

The Aeronautical Operating Systems Office (Code RO) of NASA's Office of Aeronautics and Space Technology (OAST) is responsible for overall direction, funding and evaluation of the Terminal Configured Vehicle Program.

Langley Research Center is responsible for implementation management of the TCV Program with support from Wallops Station. A TCV Program Office has been established under the Electronics Directorate. Reporting will be through the Director for Electronics to the Center Director. These management relationships are illustrated in figure 8.

A technical Steering Committee has been formed at LRC to provide advice and management assistance to the TCV Office in both program and organizational matters.

A Flight Experiments Working Group is responsible to the TCV Office for soliciting, coordinating, and assessing appropriate experiments for the TCV effort and for recommending experiments and plans and changes in plans to accomplish the experimental effort. This group will be chaired by LRC with members from FAA, FRC, ARC, Wallops Station, and LeRC.

The NASA Research and Technology Advisory Council, Committee on Aeronautical Operating Systems, has been requested to establish an advisory panel for providing recommendations and reviews of the TCV activities on a continuing basis. The advisory panel will consist of airline management and pilot personnel, aircraft and avionics manufacturers, DOT and FAA representatives, OAST personnel, and others as appropriate. The advisory panel will interface directly with the TCV Program personnel as well as report to its parent advisory committee and OAST Headquarters.

G.1.1 TCV PROGRAM OFFICE

The TCV Program Office will be composed of a Chief, Assistant Chief, several technical generalists, an administrative operations specialist, and a secretarial assistant. The chief and his staff are responsible for the overall direction for preparation, maintenance, and execution of program plans, budgets, manpower resources, schedules, and reports to research centers and OAST program office management; interagency and industry coordination; review and approval of experiment planning; travel coordination; and implementation of systems studies.

G.1.2 PROGRAM IMPLEMENTATION TEAM

The Program Implementation Team will be composed of disciplinary and operational representatives from the research and engineering divisions, and supporting research, technology, and engineering personnel to carry out activities in the following areas: flight experiments, avionics, simulation, advanced systems and aerodynamics, systems engineering, man-vehicle technology, and Wallops Station support. Activities in additional areas (e.g., propulsion, structures and materials) may also be required as the program evolves. To communicate and function effectively in daily operations, the team managers and personnel will establish and carry out the necessary coordination and interface activities with their associates in other areas. Maximum freedom will be delegated to the team managers, consistent with efficient program control and sensitivity to the assignments and prerogatives of others. To assure adequate program visibility, the managers will report periodically (daily, weekly, etc.) as required to the TCV Office as to the situation and status of activities.

The organization described will permit an orderly and integrated effort to be brought to bear on the multi-disciplined R & T required in the program and will best utilize the capabilities and experience existent in the Langley Research and Engineering Divisions.

G.2 MANAGEMENT REVIEW AND REPORTING

G.2.1 PROGRESS REVIEWS

Progress reviews will be held as follows for the purpose of obtaining and transferring information concerning technical progress, status, problems, future events, schedules, and resources. Daily contacts between the personnel of the line divisions will ensure communication at the working levels. Weekly program reviews conducted by the TCV Office will effect communications with the Implementation Team Managers and pertinent line personnel. Information flow to the Electronics Directorate will be accomplished in bi-weekly status reports and to the Center Director in monthly program reviews. Reviews for the Technical Steering Committee will be on a special call basis, as required. The Flight Experiments Working Group will meet at the call of the Chairman, 3 to 4 times per year. The RTAC Advisory Panel will also meet at the call of its Chairman as deemed appropriate. Progress reviews of major contractor efforts will be scheduled by the TCV Program Chief.

Special progress reviews will be held at the completion of significant program events. Some selected key events currently identifiable are as follows:

EVENT	REVIEW DATE
Terminal Area ATC Simulation Sensitivity Study Results Report	December 1973
Results of Advanced Electronic Displays Flight Evaluation on RSFS (FAA/NASA/Boeing)	February 1974
RSFS Delivery to NASA LRC	April 1974

EVENT	REVIEW DATE
ATT Reduced Range RTOL Terminal Area Compatibility Study Final Oral Report	January 1975
3D/4D Curved Approach Simulation and Flight Test Results	April 1975
Initial Results of Operational Systems Evaluation Simulation and Flight Test Results	June 1976
Category III Landing Simulation and Flight Test Results	November 1977
Detailed Results of System Evaluation Simulation and Flight Test Results	December 1978
Results on Cooperative FAA/NASA Flight Tests on: EADI, ILM, Category III Data Collection, Area Navigation, and MLS Utilization	To be scheduled

The TCV Program Chief will provide data to the OAST Aeronautical Operating Systems Office Director for Program Reviews in OAST and will participate as required in these program reviews.

G.2.2 STATUS REPORTS

The Program Chief will issue monthly program status reports (MICS, Level 2) which will contain a narrative description of progress and accomplishments, a milestone schedule showing status of key events, funding status, manpower, problem areas requiring higher management attention, recommended corrective actions, and any other pertinent information conveying the current status of the program. This report will be disseminated to management within OAST and the OAST Research Centers.

The Contractor Financial Management Reporting System (utilizing 533 series reports) will be used to set, maintain, and report on financial and manpower resources. Status reports on all resources and accrued and planning costs will be included in the monthly MICS report. The key financial and manpower ceilings controlled by Headquarters are discussed in Section J, Resources Schedule.

G.3 FLIGHT SAFETY, RELIABILITY, AND QUALITY ASSURANCE

During flying operations, all due safety precautions will be observed. Although much flying will be done by using the palletized flight station and other automatic systems, appropriate monitoring will be undertaken by safety pilots in the normal crew station. Either safety crew, upon detection of a malfunction, will disconnect the experimental systems and take control of the aircraft and fly it, using the aircraft's basic flight systems. This capability will not be impaired during the conduct of the experimental programs. All new equipment and instrumentation installation will be approved by the Quality Assurance Office (RAFD). A review of the flight program by a selected Aviation Safety Committee will be conducted and safety procedures established and followed during the flight program. Operational control of the aircraft during test operations will rest with the Operations Branch, RAFD. In a functional sense, the Head, Operations Branch, will be responsible for flight safety. Final decision authority during any particular flight will rest with the designated senior NASA research pilot aboard. Appropriate coordination with Wallops Station Range Safety Officer will be accomplished prior to flying individual experiments to insure compliance with Wallops Airport safety standards.

H. PROCUREMENT STRATEGY

The procurement strategy to be employed presumes the use of existing equipment and facilities to the maximum extent possible, particularly in the initial phases of the program, with such additions or modifications required to adapt the equipment to the special needs of the research activities. Examples of the existing facilities are:

LRC Computation and Simulation Complex

Display Research Facility (also being used by VALT Program)

Guidance System Simulation Facility

Items of equipment essential to the program that have been adequately analyzed, justified, and specifications developed to minimize risks will be procured in a timely manner. Examples are:

B-737 Aircraft	FY-73
Research Support Flight System (B-737 with special equipment)	FY-74

Dedicated Simulator Cab	FY-74
Simulation Support Equipment	FY-73
Wallops Station - LRC Data Tie-Line	FY-74
Airborne Up-Down Data Link	FY-74
Experiment Support and Integration	FY-75

Items that involve higher risks or require additional study will be deferred until adequate justification and specifications are developed. Examples are:

Operational Requirements Study	FY-75
Independent Landing Assessment System (imaging radars, multiple displays, etc.)	FY-74 or 75
Airborne MLS Interface Equipment	FY-75
Microwave Landing System Production Prototype	FY-76
Airborne Inertial/Strapdown Navigation System Development	FY-75
High-Speed Runway Turnoff at Wallops Station	FY-75 or 76
RSFS Advanced Flight Control Capability	FY-76
Roll-Out Guidance System	FY-76
Fail-Operational System Development (including digital whole-word automatic control system, redundant automatic control system, redundant navigation and display computer, etc.)	FY-75 or 76

Procurement of the systems and associated hardware will be accomplished in accordance with established NASA policies, procedures, regulations, and instructions.

I. MILESTONE SCHEDULE

The major milestone is the flight demonstration of an integrated system in about six years from program approval. The extent to which this can be accomplished will be dependent on funding limitations. The schedules shown for specific elements are tentative, since some of them depend upon the availability of research results and/or experimental hardware being developed on other programs. For example, a cooperative program has been agreed upon with DOT-FAA for the flight evaluation on the RSFS of some experimental hardware resulting from the SST Phase II Technology Program. The schedule for delivery of these items directly affects some major milestones of the TCV Program.

A summary of major program schedule milestones follows:

<u>July 1973</u>

Acquire B-737. Accomplished

<u>August 1973</u>

Initial simulator facility in operation. Accomplished

<u>February 1974</u>

Complete ADEDS demonstration flights by FAA/Boeing

<u>March 1974</u>

Complete supplemental test flights on AGCS

<u>April 1974</u>

RSFS delivery to Langley

Complete installation and checkout of all ground support facilites

Initiate flight investigation of approach paths

Complete validation MLS simulator

<u>September 1974</u>

Complete validation of RSFS simulator

Complete preliminary investigation of displays and controls for new approach paths

<u>August 1975</u>

Complete operational requirements and sensors study

<u>October 1975</u>

Complete RSFS simulator studies

Complete 4D precision flight path investigations

May 1976

Complete approach noise procedure flights

September 1976

Complete CAT III landing flights

August 1977

Complete system evaluation flights

As experience is acquired, these milestone dates will be reviewed and updated. Maintenance of the schedule is also predicated on the availability of funds and manpower as listed in the Resources Plan.

J. RESOURCES SCHEDULE

The individual tasks mentioned earlier have been assessed to determine the funding and manpower requirements for accomplishment within the desired schedule. A summary of the expected requirements is shown in Table 1. These numbers are believed to be reasonably accurate for the first two fiscal years, but of less accuracy thereafter. The estimates will, of course, be updated as the program proceeds and experience is gained. Tables II and III give a further breakdown by program elements, with the major items of cost in each element listed. Major issues for management consideration with respect to schedule changes or additional resource requirements are addressed in the Risk Assessment (reference 15).

K. FACILITY REQUIREMENTS

Facilities available for use in the program include avionic research, computational, flight, and simulation facilities at Langley and Wallops Station. These will be supplemented with equipment required to accomplish this program.

K.1 RESEARCH SUPPORT FLIGHT SYSTEM (B-737-100)

An essential aspect of the current program is the design and demonstration of aircraft and equipment technology of flight controls, displays, automatic systems, and techniques required to make CTOL and RTOL civil transport aircraft compatible with advanced air traffic systems. In order to provide authenticity to these evaluations and demonstrations, a typical civil air transport aircraft fitted with systems for actual airline adverse weather service is required. After a careful review of all aircraft types, the Boeing 737-100 was selected. The aircraft is the smallest fanjet in trunk-line service and provides better ratios of lift to drag at high lift than any other commercial aircraft of comparable size. (This consideration is of extreme importance when noise and high performance levels in the terminal area are of concern.) In addition, the aircraft is equipped with modern, powered flight controls which allow for advanced automatic landing systems installation and evaluation. An investigation of available aircraft showed that this aircraft best fitted the requirements of the program and furnished the most economical research facility when acquisition, modification, and operating costs were considered. Advanced flight control equipment (some already available from an FAA-funded SST Technology Program) will be assembled on pallets. The obvious advantages of this arrangement are rapid removal and installation on the aircraft, accessibility, and minimum interference with other on-board experiments. Placement of equipment in the aircraft is illustrated in figure 6; an aft flight deck will be installed as shown for research purposes. The airplane will be operable from this cockpit for research on displays, controls, etc., under simulated Category III operations, with safety assured through monitoring and take-over capability by the forward cockpit crew. The ADEDS display equipment is easily removable and transferable to the forward cockpit for actual low visibility operations.

K.2 COMPUTATION AND SIMULATION FACILITIES

The LRC computation and simulation facilities are used in research programs which require analytical and engineering studies, mission analysis, research data processing, and real-time simulation. The basic elements of this facility include an integrated multicomputer complex controlled by a front-end executive computer and various cockpit simulators of varying degrees of complexity including a dual, fixed-base simulator, designated as the Differential Maneuvering Simulator. Other facilities include a visual landing terrain scene generator, a capability for generation and display of computer-derived graphics and special displays, and an airport terminal area simulation for air traffic systems studies.

Although an interim simulator has been assembled at Langley to accommodate the initial program studies, a dedicated simulator cab will be required to support the program as the flight activity increases. The simulator will be used to: (a) explore preliminary concepts of advanced flight procedures, controls, and displays; (b) provide pilot familiarization with advanced piloting techniques, crew roles and duties, and thus aid program implementation planning; (c) provide a mechanism through which interested parties outside NASA can see and evaluate program technical activities; (d) reduce the total number of flight hours required; (e) provide ground research in advance of flights with new configurations as a matter of safety; (f) validate flight software; (g) refine the flight experiments; and (h) investigate off-normal flight situations. It is anticipated that the dedicated simulator cab will be a duplicate of the aft cab on the RSFS and can be procured in FY-74 and be operating in CY-74

K.3 DISPLAY RESEARCH FACILITY

To provide proper development and formating of pilot displays, LRC has developed a flexible display generation system. The system is housed in a trailer and has been used at LRC and Wallops Station to generate and transmit via a TV link, candidate display formats to simulators and to research aircraft under operational conditions. During test periods, the system derives aircraft position data from an FPS-16/Laser Tracker at NASA's Wallops Station airport, and flight parameters from on-board sensors which are telemetered to the ground (figure 7). Display symbologies, which are functions of these data, are generated on oscilloscopes by a digital computer. Static display images, which are functions of this chosen display format, are generated with the use of back-lighted photographic transparencies. Television cameras, which view these static and dynamic scenes (as well as conventional flight instruments), convert the images into a standard television format for mixing, and the composite picture is transmitted to a simple airborne receiver-monitor. This facility will be used as needed in the ground-based and in-flight simulations noted previously.

K.4 GUIDANCE SYSTEM SIMULATION FACILITY

A modified FPS-16, high-precision radar (see section F.1.4) is in operation at the Wallops Island Station. The flexibility of this system, when coupled with a precision laser tracker, will allow simulation of either scanning-beam or Doppler microwave landing system guidance information through touchdown. This information will be used to develop aircraft systems and displays suitable for landing and takeoff in the advanced air traffic control system. Computer software design and development and hardware specifications are currently underway.

L. REFERENCES

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4. The Long Range Needs of Aviation. Report of the Aviation Advisory Commission. January 1973.

5. Advanced Subsonic Long-Haul Transport Terminal Area Compatibility (TAC) Study. NASA Contract NAS1-12018.

6. The Crystal Ball Focuses on the Next Generation of Transport Aircraft. SAE Paper 710750, Sept. 1971, Richard E. Black, David G. Murphy, and John A. Stern, Douglas Aircraft Company.

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9. Economic Impact of Air Traffic Congestion Growth. Paper presented at SAE Conference on Air Transportation, April 21, 1970. P. J. Zegan, Eastern Airlines, Inc.

10. Joint DOT/DOD/NASA Planning Group, National Plan for Development of the Microwave Landing System, July 1971.

11. Agreement Between the Federal Aviation Administration and National Aeronautics and Space Administration Concerning Cooperation to Achieve Improved Terminal Area Operations, May 3, 1973.

12. STOL Operating Experiments, Final Report of the Flight Experiments Committee of the Joint DOT/NASA STOL Operating Experiments Steering Group, July 21, 1972.

13. Project Development Plan for the Digital Fly-By-Wire Experimental Program, Flight Research Center, February 16, 1973.

14. Joint FAA/NASA VLF (Omega) Program, Memorandum from Head, Telecommunications Branch, FID, Langley to NASA Headquarters, Attn: Lee D. Goolsby, March 29, 1972.

15. Risk Assessment for Terminal Configured Vehicle Program, December 1, 1973.

TABLE 1

TERMINAL CONFIGURED VEHICLE

PROGRAM RESOURCE REQUIREMENTS (RTOP'S 768-81-01 & -02)

	FY 72	FY 73	FY 74	FY 75	FY 76	FY 77	FY 78	FY 79	TOTALS
DIRECT MANPOWER (HEAD COUNT)									
Manpower	6	37	51	56	58	58	47	47	360
FUNDING REQUIREMENTS (K DOLLARS)									
Released Funds	280	1,910	4,000	4,950	4,800	3,904	1,461	1,661	22,966
Reserve	-0-	-0-	-0-	350	300	250	200	-0-	1,100
Net R&D	280	1,910	4,000	5,300	5,100	4,154	1,661	1,661	24,066
IMS	80	530	1,000	1,000	1,000	846	339	339	5,134
TOTAL R&D	360	2,440	5,000	6,300	6,100	5,000	2,000	2,000	29,200
R&PM Resources	221	1,362	1,856	2,032	2,111	2,111	1,711	1,711	13,115
TOTAL VALUE	581	3,802	6,856	8,332	8,211	7,111	3,711	3,711	42,315

TABLE II

FY 1973 FINANCIAL SUMMARY

	OBLIGATIONS	COSTS
Terminal Area Environment Modeling and Simulation	120	101
Research Support Flight System (RSFS)	1250	1250
Aircraft Instrumentation	95	54
Simulator Graphics Display Equipment . . .	280	-0-
MLS Feasibility Models Installation Support	60	60
Directorate Support and Miscellaneous . .	20	2
TOTAL	1825	1467
Carryover to FY 74	85	
FY 1973 NOA	1910	

TABLE III

FY 1974 FUNDING REQUIREMENTS ($K)

	OBLIGATIONS	COSTS
Terminal Area Environment Modeling and Simulation	204	217
Research Support Flight System (RSFS)	2693	2638
Aircraft Instrumentation	136	184
RSFS Operations Support	158	162
Simulator Graphics Display Equipment	-0-	280
Study of Flight Procedures for Noise Alleviation	54	56
Evaluation of Landing Assessment Systems, Requirements, Sensor Techniques, and Design Concepts .	250	166
Facility Preparation and Ground Data Handling Equipment	190	135
MLS Test Support	135	126
Dedicated Simulator Cab	260	260
Project Office/Directorate Support	5	23
TOTAL	4085	4247
<FY 1973 Carryover>	<85>	
FY 1974 NOA	4000	

TABLE IV

FY 1975 FUNDING REQUIREMENTS

	NET R&D NOA (K dollars)
Terminal Area Environment Modeling and Simulation	200
ILAS Sensors	250
Experiment Support and Integration	1,000
Operational Requirements Study	300
Interim MLS	250
Aircraft Refurbishment and Replacements	400
Boeing RSFS Field Support and Balance of Documentation Effort	400
Continuing Program Support (NPS, Studies, etc.)	700
INS Units	573
Supplemental Research Equipment (Radio, etc.)	14
Aircraft Instrumentation	50
Landing Display Software	100
Assembler Language for Display Computers	25
Flight Control Computer for Simulator	150
Control System Mods. for Decelerating Approaches	500
EADI Equipment/Modifications	200
WI/LRC Aircraft Research Facility	50
Simulation and Analysis of TCV Multipath Effects	45
Automatic Checkout System for Advanced Aircraft Instrumentation	40
Avionics Antenna	40
Project Office/Directorate Support	13
	5,300

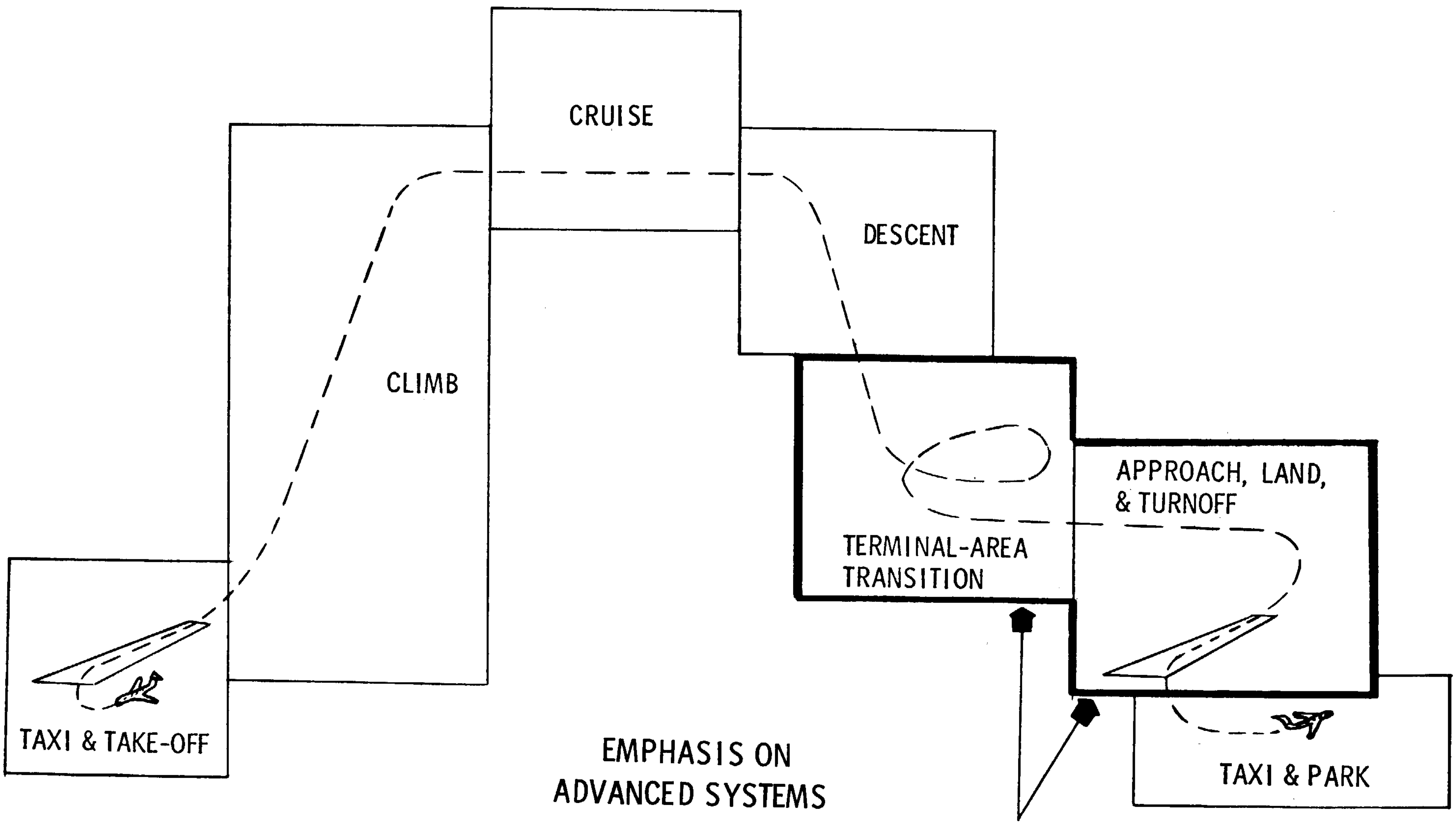

FIGURE I. - FLIGHT MODES AND AREAS OF EMPHASIS IN TERMINAL CONFIGURED VEHICLE PROGRAM

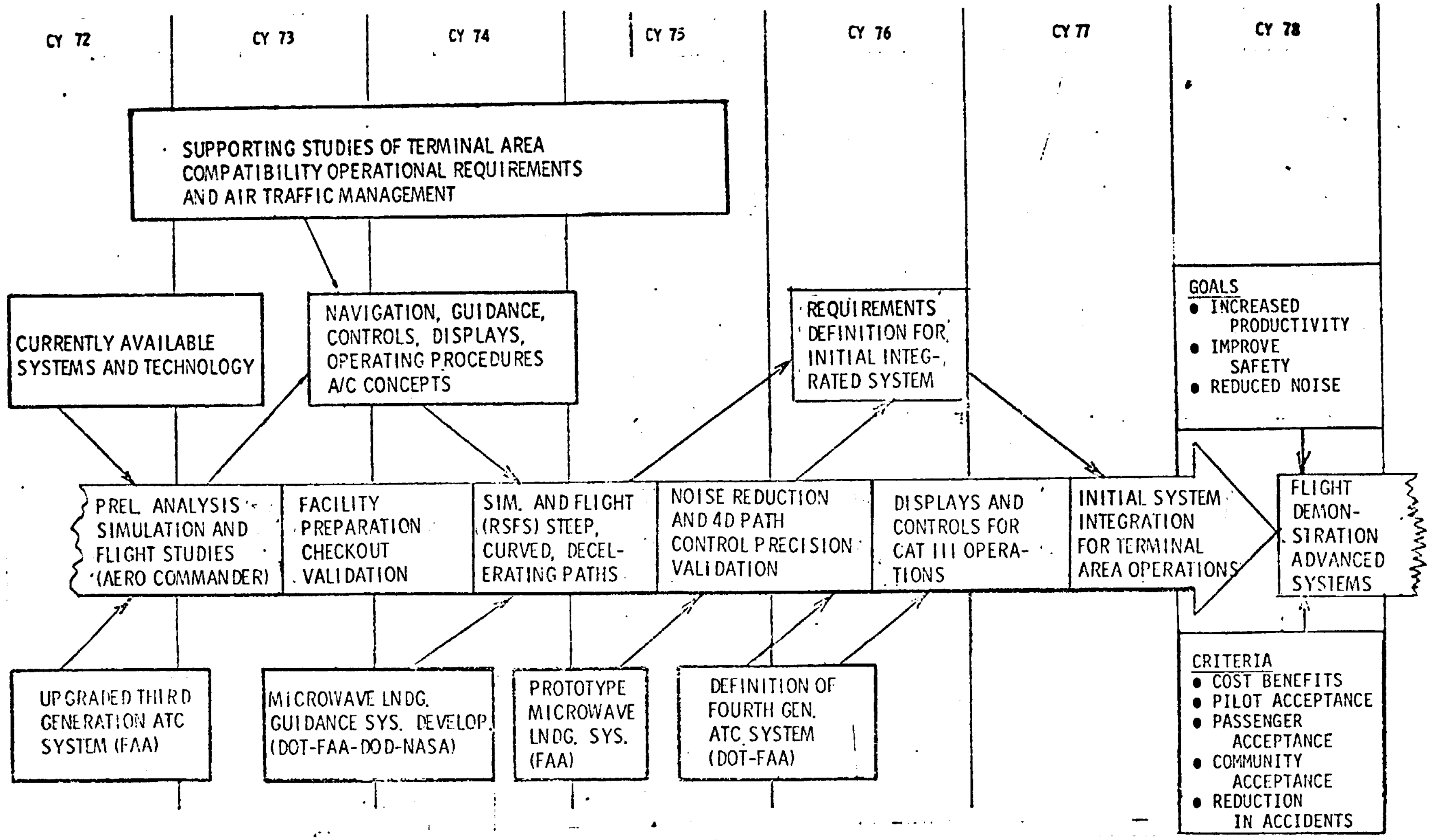

FIGURE 2. - OVERVIEW OF TERMINAL CONFIGURED VEHICLE PROGRAM

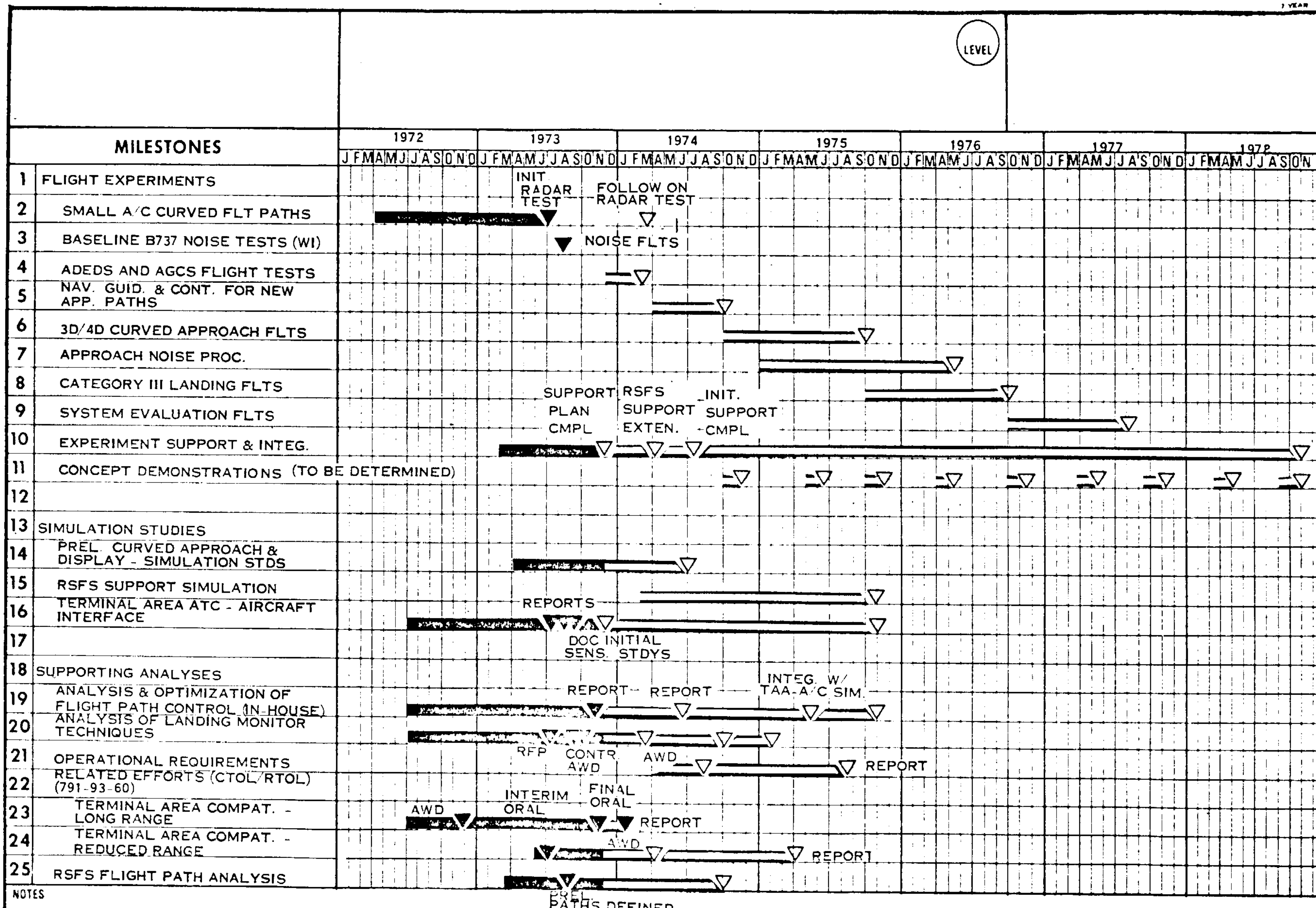

FIGURE 3. - TCV PROGRAM EXPERIMENTS, STUDIES AND ANALYSES

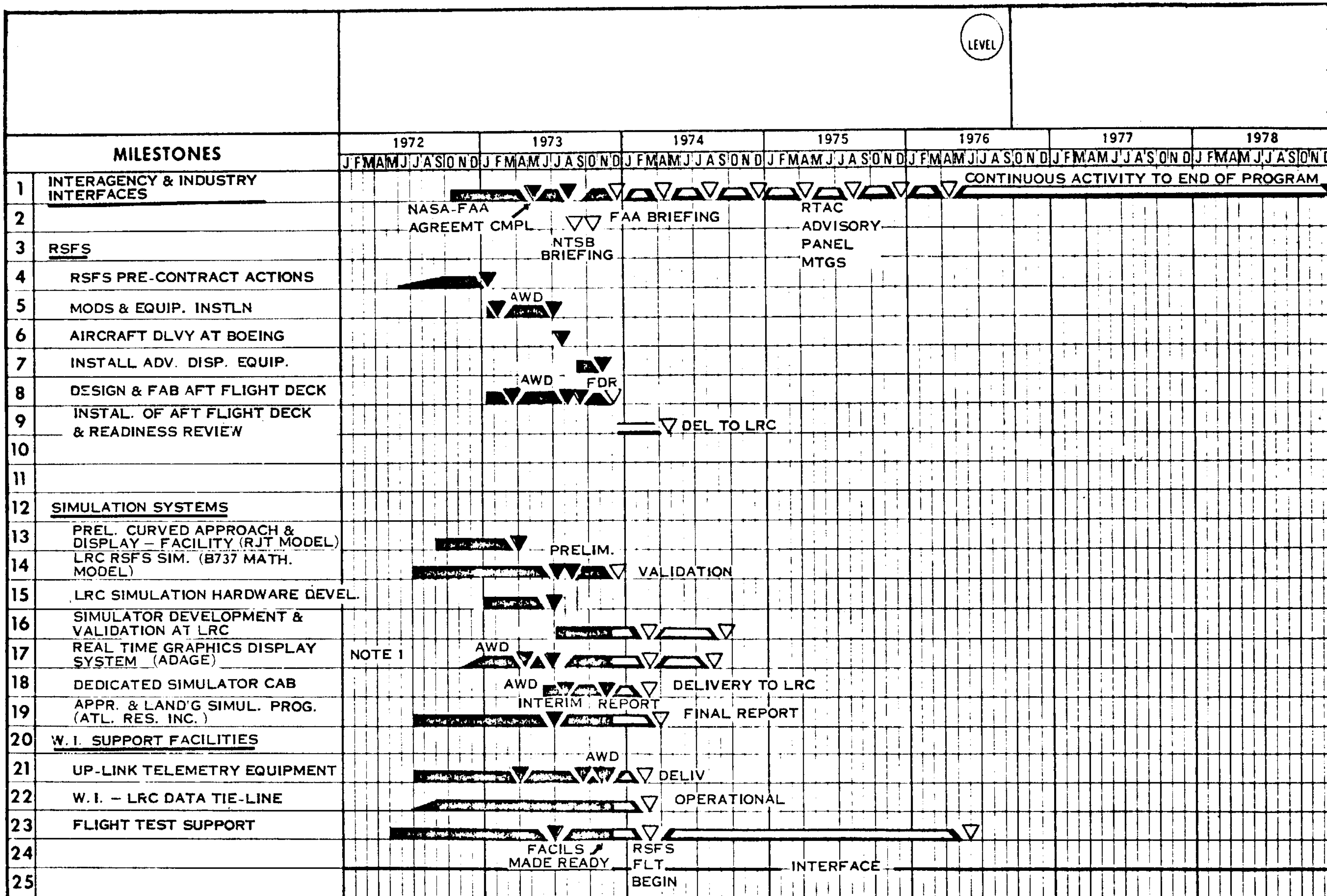

FIGURE 4. - TCV PROGRAM INTERFACES AND SUPPORT FACILITIES

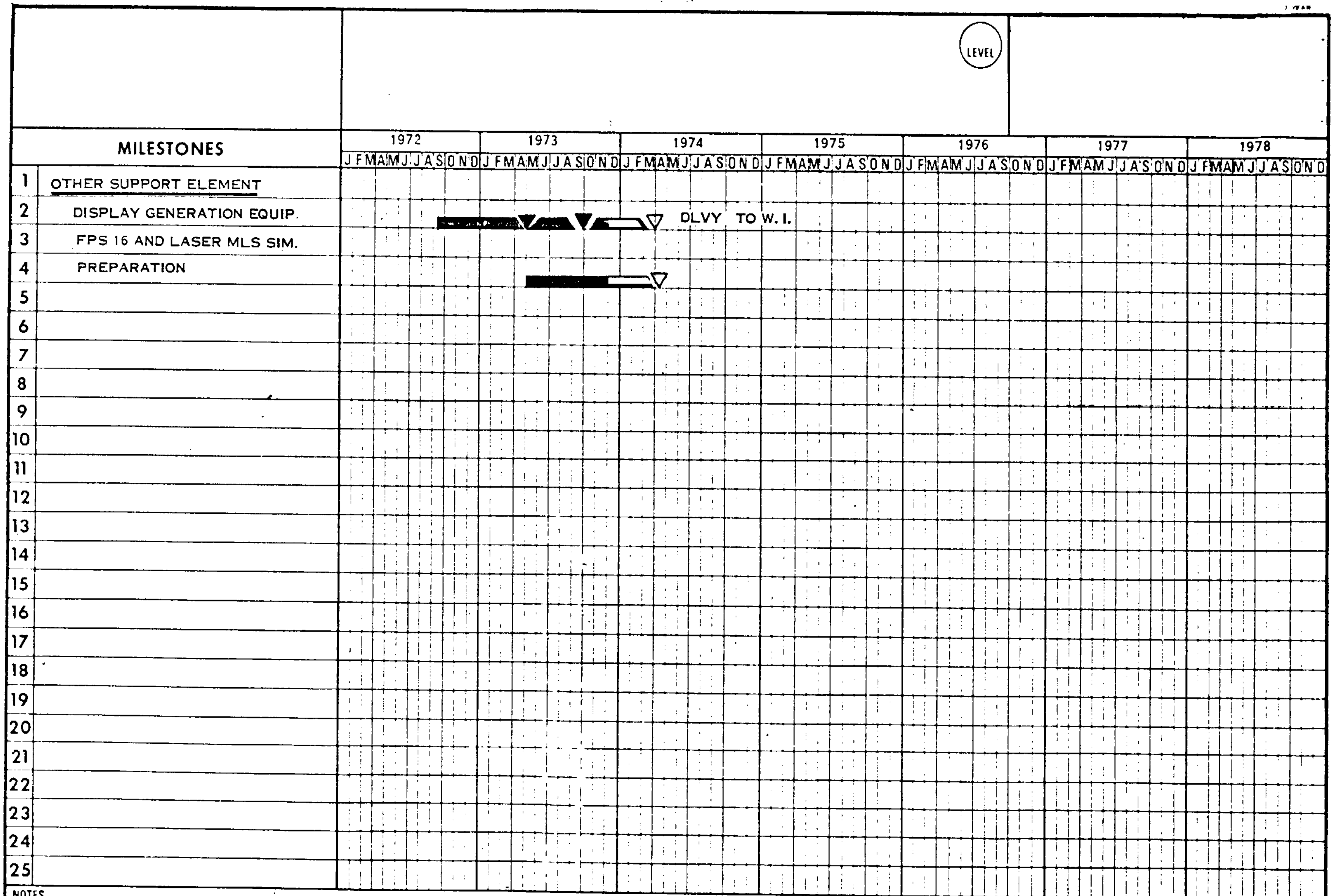

FIGURE 4. - TCV PROGRAM INTERFACES AND SUPPORT FACILITIES
(CONTINUED)

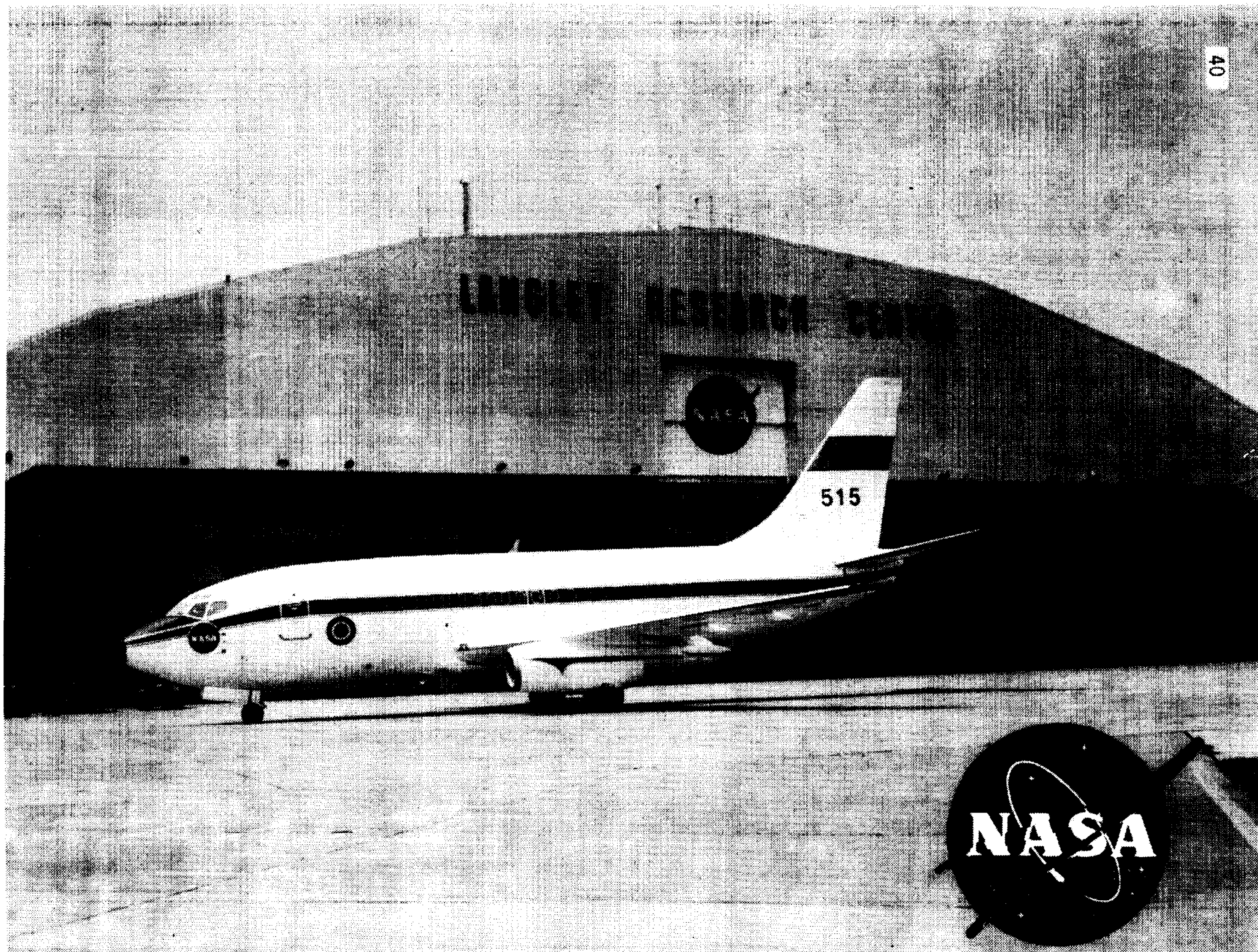

FIGURE 5. - BOEING 737 RESEARCH SUPPORT FLIGHT SYSTEM

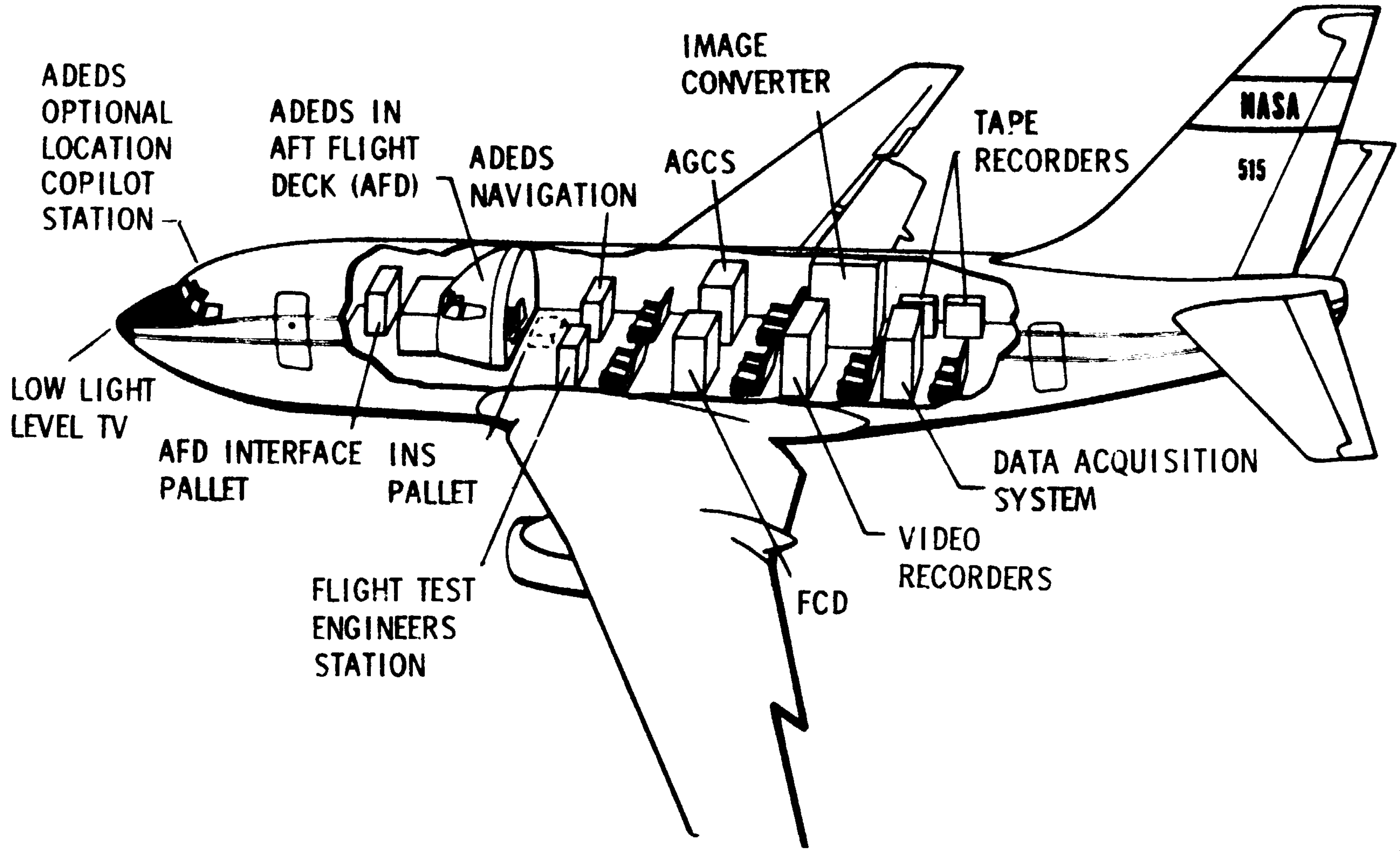

FIGURE 6. - RESEARCH SUPPORT FLIGHT SYSTEM INTERNAL ARRANGEMENTS

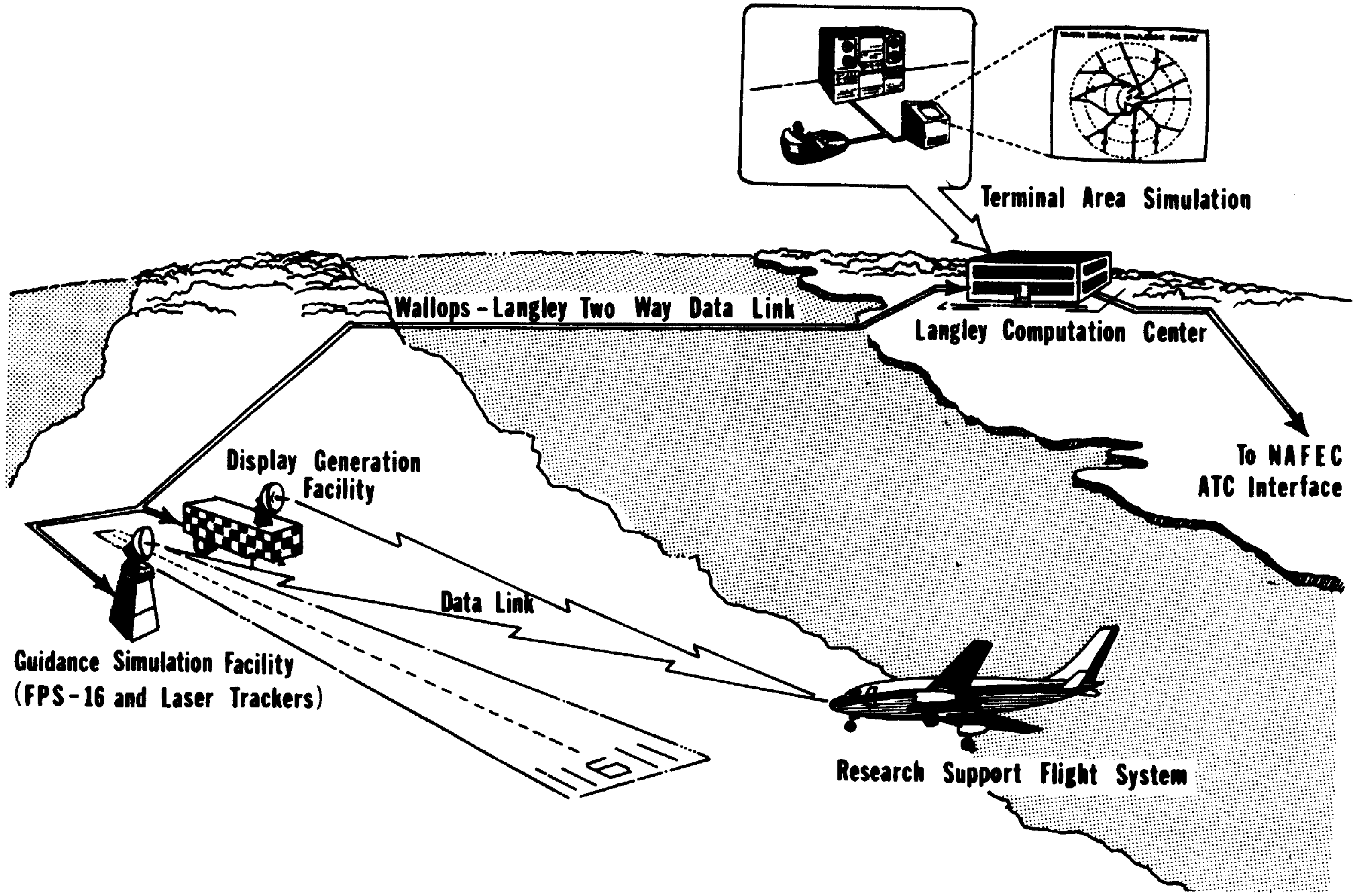

FIGURE 7. - WALLOPS-LANGLEY CTOL AIRCRAFT FLIGHT RESEARCH FACILITIES

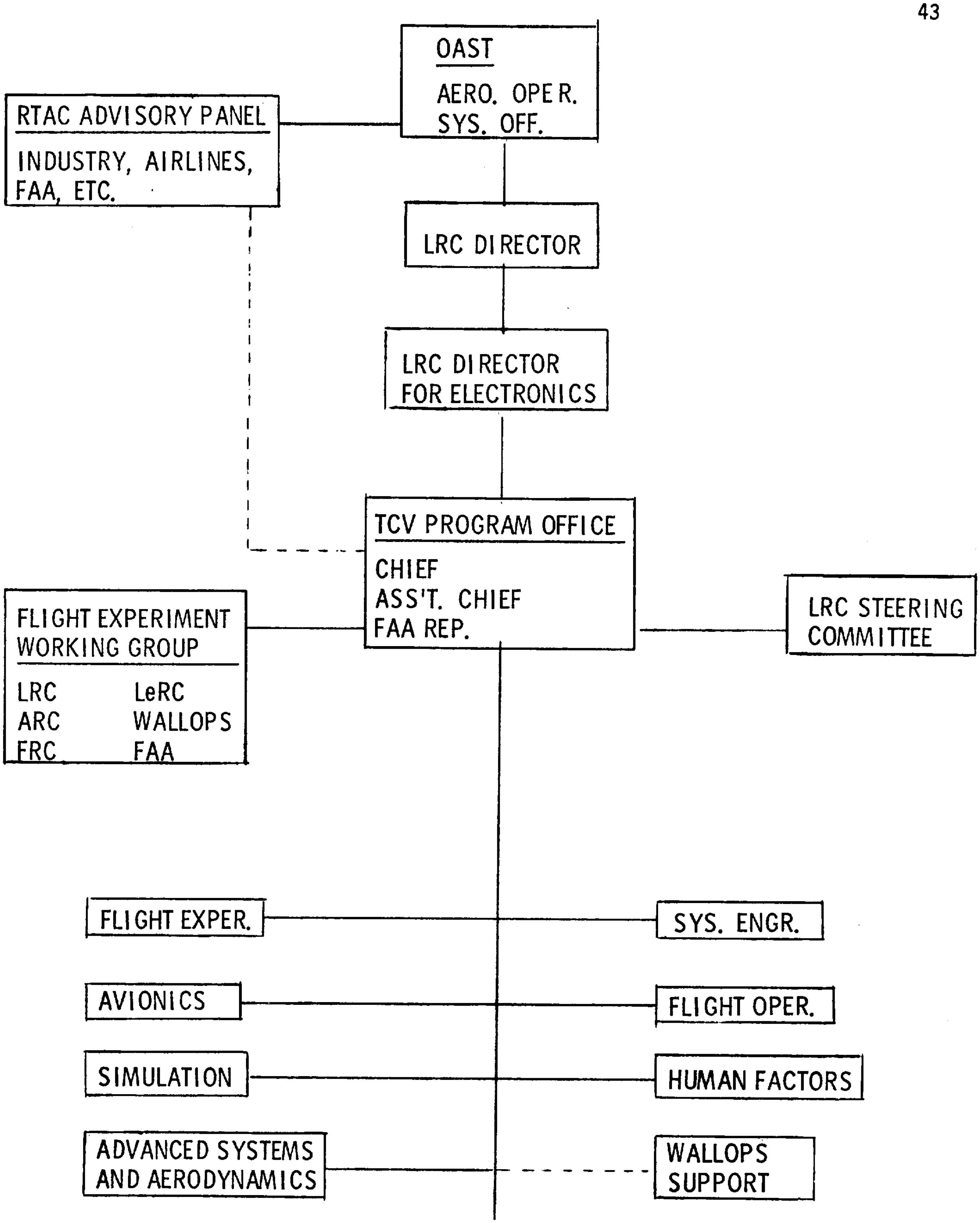

FIGURE 8. - TCV PROGRAM ORGANIZATION